

Advanced Ceramic Matrix Composites with Multifunctional and Hybrid Structures

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Abstract

Ceramic matrix composites are leading candidate materials for a number of applications in aeronautics, space, energy, and nuclear industries. Potential composite applications differ in their requirements for thickness. For example, many space applications such as "nozzle ramps" or "heat exchangers" require very thin (< 1 mm) structures whereas turbine blades would require very thick parts (≥ 1 cm). Little ~~has been investigated as to~~ ^{is known} the effect of thickness on stress-strain behavior or ^{the} elevated temperature tensile properties controlled by oxidation diffusion. In this study, composites consisting of woven Hi-NicalonTM fibers a carbon interphase and CVI SiC matrix were fabricated with different numbers of plies and thicknesses. The effect of thickness on matrix crack formation, matrix crack growth and diffusion kinetics will be discussed.

In another approach, hybrid fiber-lay up concepts have been utilized to "alloy" desirable properties of different fiber-types for mechanical properties, thermal stress management, and oxidation resistance. Such an approach has potential for the C_f-SiC and SiC_f-SiC composite systems. CVI SiC matrix composites with different stacking sequences of woven C fiber (T300) layers and woven SiC fiber (Hi-NicalonTM) layers were fabricated. The results will be compared to standard C fiber reinforced CVI SiC matrix and Hi-Nicalon reinforced CVI SiC matrix composites. In addition, shear properties of these composites at different temperatures will also be presented. Other design and implementation issues will be discussed along with advantages and benefits of using these materials for various components in high temperature applications.

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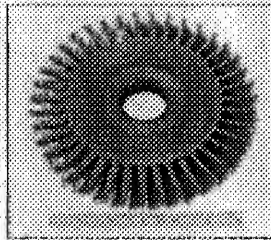
Outline

- **Introduction and Background**
- **Needs for CMCs with Hybrid Structures**
- **Advantages**
- **Experimental**
 - Composite Lay-ups and CVI
 - Elastic Moduli Measurements
 - Stress Rupture Testing
 - Microstructural Characterization (Optical, SEM)
- **Results and Discussion**
 - Thermomechanical Behavior
 - Microstructural Analysis
- **Summary and Conclusions**

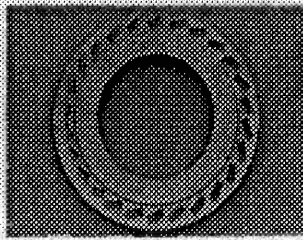
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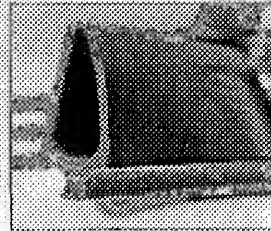
Ceramic Matrix Composites Components for Aerospace Systems



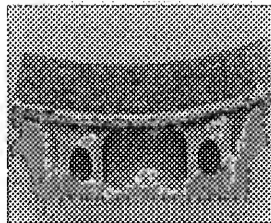
Turbine Rotor



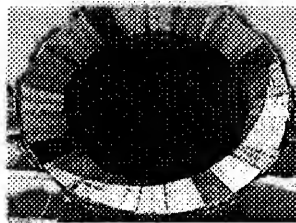
Turbopump Stator



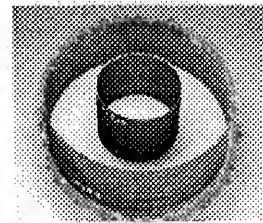
Turbine Rear Frame
Leading Edge



Interstage Shroud



Nozzle Flaps and Seals

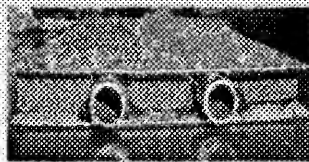


Combustor Liner

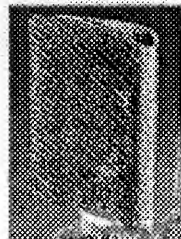
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Need of Ceramic Composites with Varying Thickness and Hybrid Structures

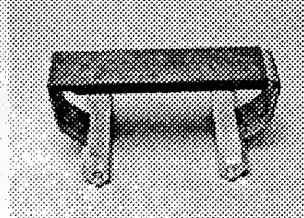


Advanced Composites for
Radiators

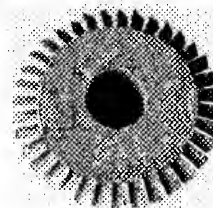


Composite Vane for
Aeroengine

Composites
with varying
thickness and
architecture are
needed



Cooled Panels for Nozzle Ramps



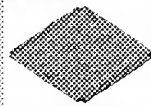
Composite Blisks

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Approaches to Composite Fabrication

GE Power Systems Composites, Newark DE



2D lay-up fixed in tooling

CVI BN or C Infiltration

Interphase deposition, then removal from tool

CVI SiC Infiltration

Dog Bone Tensile Bars Machined

Cut into Rectangular Shapes

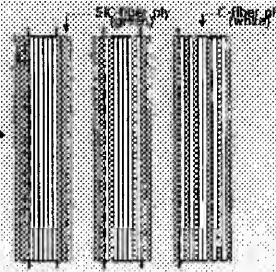
Epoxy Infiltrate

Tensile Bars Machined

Final CVI SiC Infiltration

8, 30, & 36 ply Standard Panels

8 ply Epoxy-Infiltrated



CVI BN or C Infiltration

CVI SiC infiltration, removal from tool and *delamination*

Straight-Sided Tensile Bars Machined

1, 2, and 3 ply Delaminated Panels

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Composites with Hybrid Lay-up

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Potential Benefits of Hybrid Lay-Up in Ceramic Matrix Composites

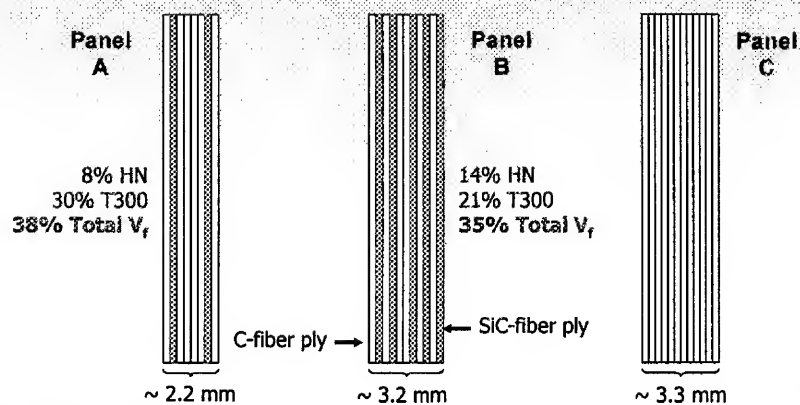
- Vary plies (fiber-types) to manipulate residual stress and matrix cracking
- Create "oxidation fire-walls" to slow down oxidation of C-fibers
- Can manipulate ply sequence for thermal-degradation (e.g., > SiC fibers on cold side and > C fibers on hot side) or residual stress-management

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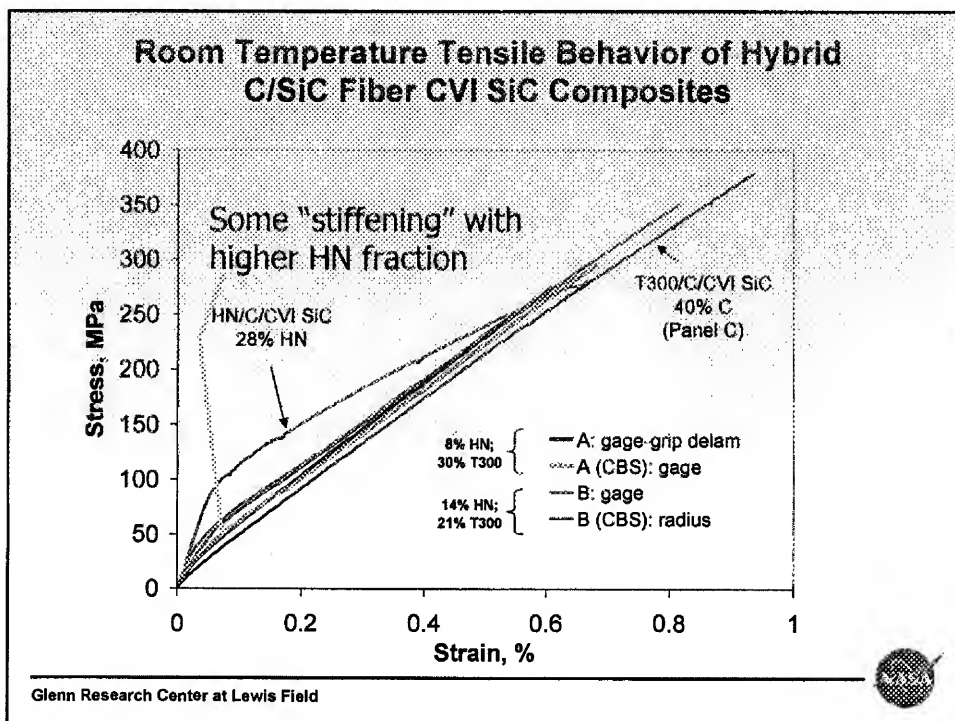
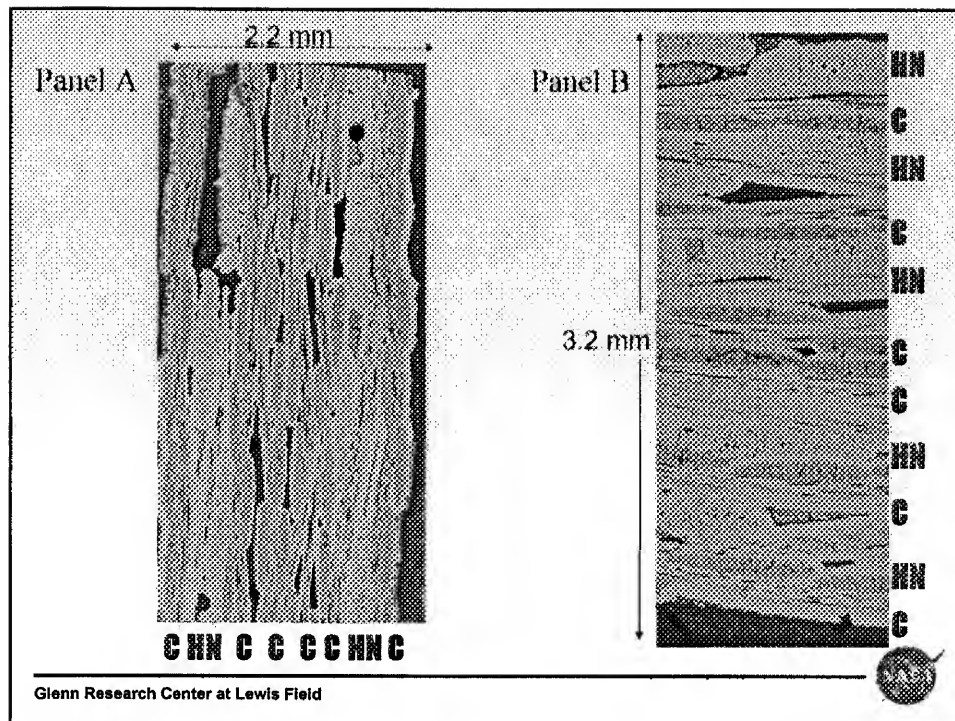
Tested Panels of Hybrid C/SiC Fiber CVI SiC Composites

- 20 "EPM" dogbone specimens for each (12.6 mm in grip; 10 mm in gage)
- ½ the dogbone specimens seal-coated with SiC and the other ½ seal-coated with CBS coating
- RT tensile with acoustic emission and elevated temperature stress-rupture tests were performed in air

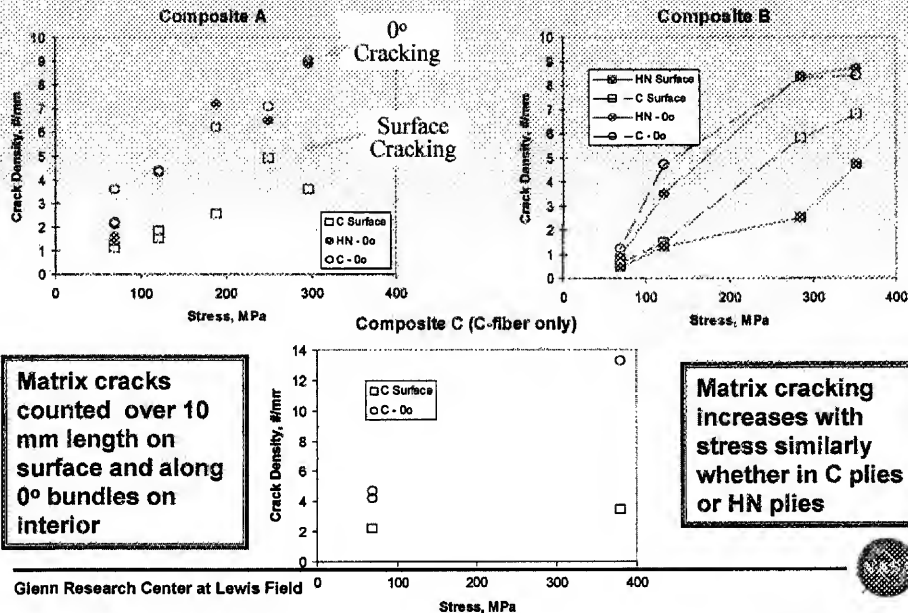


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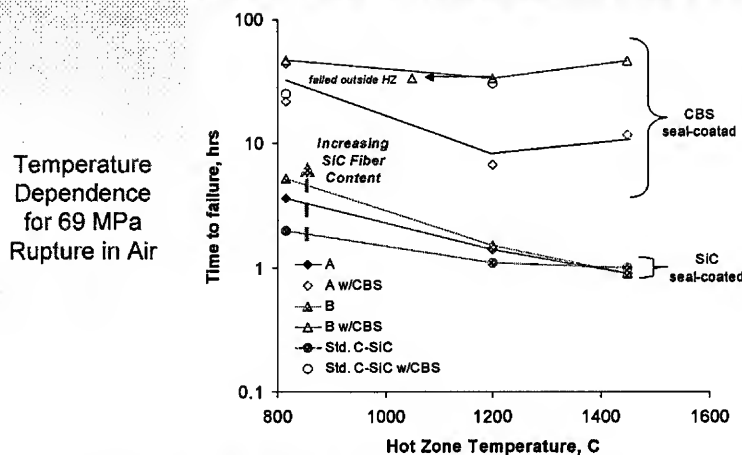




Matrix Cracking in Hybrid C/SiC Fiber CVI SiC Composites



High Temperature Stress-Rupture Behavior in Air for Hybrid C/SiC Fiber CVI SiC Composites



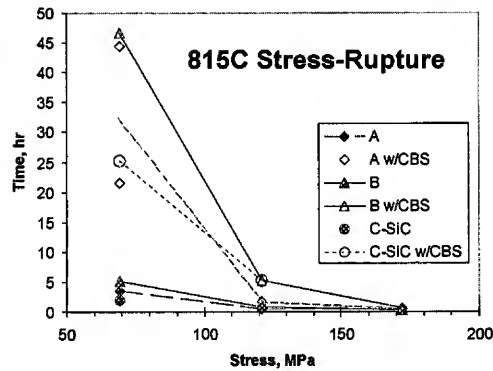
CBS coating provides best benefit at low stresses – no discernable difference for different fiber contents

Some benefit with more HN fibers for specimens not coated with CBS

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High Temperature Stress-Rupture Behavior in Air for Hybrid C/SiC Fiber CVI SiC Composites

Stress
Dependence
for 815°C
Rupture in Air



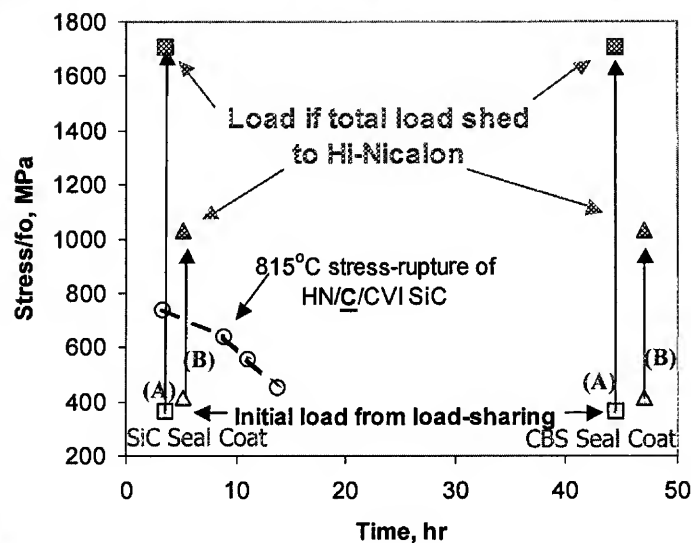
CBS coating provides best benefit at low stresses – no discernable difference for different fiber contents

Some benefit with more HN fibers for specimens not coated with CBS

2+ low 5

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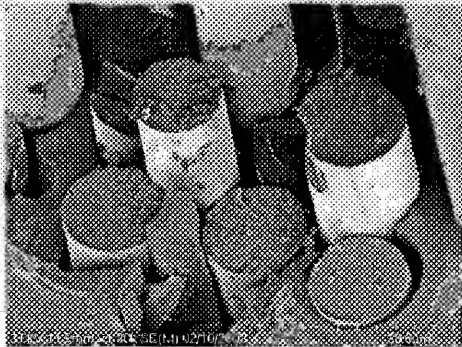
Increased loading of HN in C+HN/SiC due to
oxidation of C fibers will be too great to
significantly prolong rupture life in air



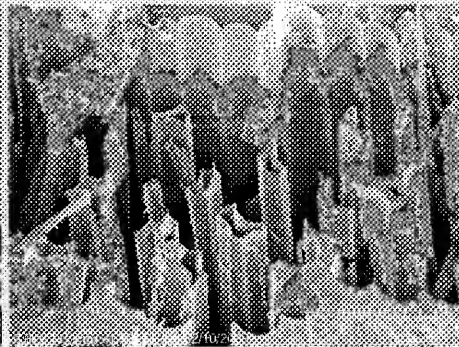
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Typical Fiber Fracture Surfaces (HN) or Lack Thereof (T300)

(A) SiC Seal-coat; 815°C 3.6 hr Stress-Rupture



Hi-Nicalon

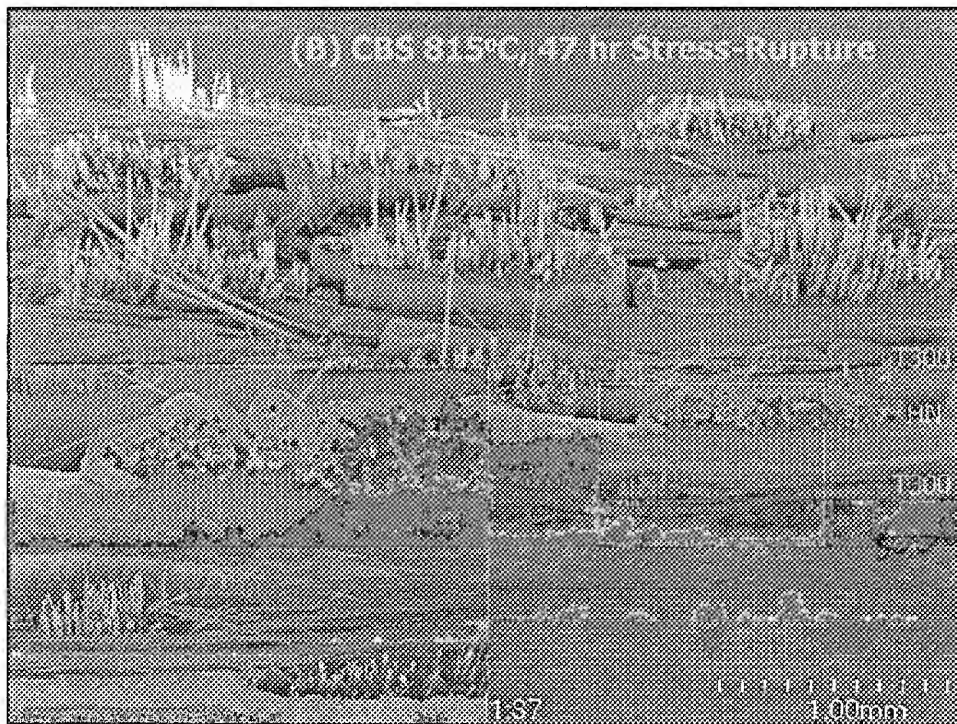


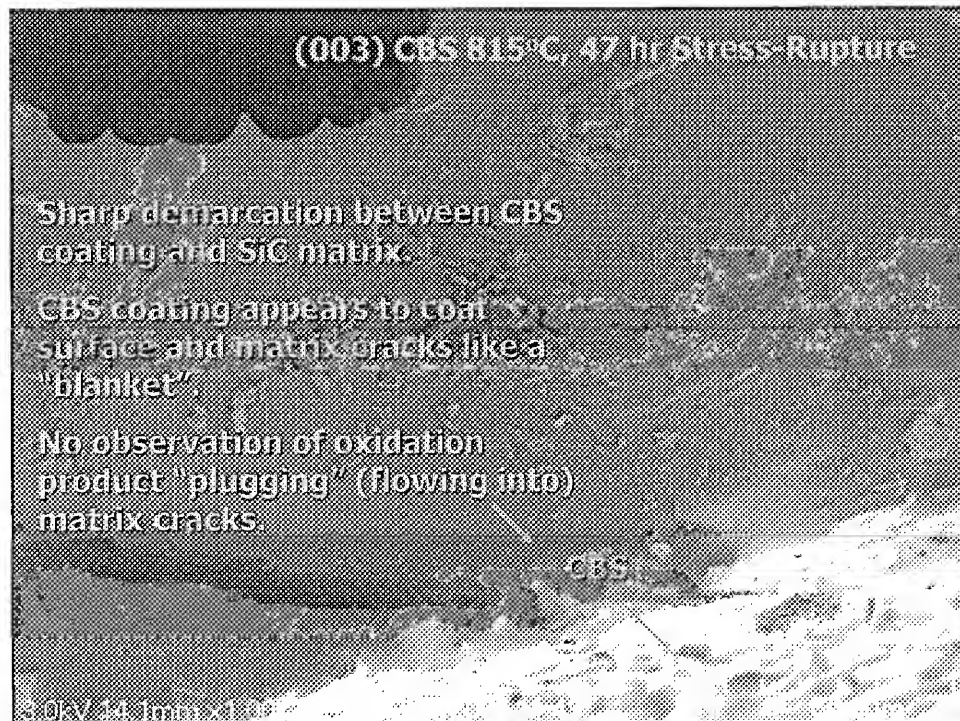
T 300 Carbon

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(B) CBS 815°C, 47 hr Stress-Rupture





Composites with Hybrid Lay-up

Summary and Conclusions

- Composite plates with alternating C and HiNicalon fiber plies could be fabricated with some delamination – probably better suited for tube-shaped structures
- HN plies do increase stiffness; however, this is mostly due to higher modulus of HiNicalon
 - *Matrix cracking occurred at low stresses for all of the C fiber-containing composites*
- Minor intermediate temperature stress-rupture improvement observed for HiNicalon containing composites
- CBS coating significantly improves stress-rupture life at low stresses, regardless of C and HiNicalon content



Effect of Composite Thickness on Thermomechanical Behavior

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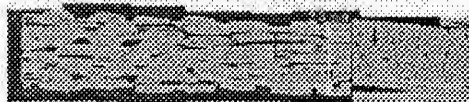
Microstructure of Hi Nicalon SiC-CVI SiC Composites



1 Ply Longitudinal Section



3 Ply Longitudinal Section



8 Ply (BN1) Cross-Section



E8Ply-8HS(BN) Longitudinal Section



30 Ply Longitudinal Section

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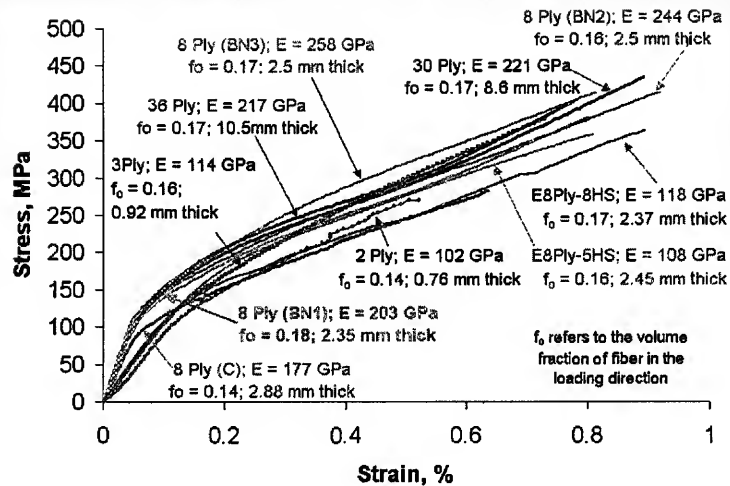
Physical Properties of Composite Specimens

Specimen	Weave	Specimen shape	l , mm	t	f_v	f_{90}	f_p
Standard 8 Ply Panels							
8 Ply (C)	8HS	dog A	2.92	0.28	0.13	0.44	0.16
8 Ply (BN1)	8HS	dog A	2.35	0.35	0.05	0.36	0.21
8 Ply (BN2)	5HS	dog B	2.50	0.31	0.06	0.46	0.15
8 Ply (BN3)	5HS	dog B	2.38	0.33	0.05	0.47	0.15
Standard Thick Panels							
30 Ply (C)	5HS	dog B	8.60	0.34	0.04	0.45	0.17
36 Ply (C)	5HS	dog B	10.50	0.34	0.04	0.43	0.19
Delaminated Thin Panels							
1 Ply (C)	5HS	Straight	0.38	0.26	0.04	0.26	0.41
2 Ply (C)	5HS	Straight	0.73	0.28	0.04	0.33	0.35
3 Ply (C)	5HS	Straight	0.62	0.32	0.04	0.35	0.29
Epoxy Infiltrated Panels							
E8Ply-5HS(BN1)	5HS	dog B	2.45	0.32	0.05	0.25	0.38
E6Ply-5HS(BN2)	5HS	dog B	2.45	0.32	0.05	0.27	0.35
E8Ply-8HS(BN)	8HS	dog B	2.37	0.33	0.05	0.29	0.33

- a Dogbone tensile specimen 203 mm in length, approximately 15.5 mm in width at grip section and 10.3 mm in width at gage section
b Dogbone tensile specimen 152 mm in length, approximately 12.6 mm in width at grip section and 10.3 mm in width at gage section
c Straight-sided tensile specimen 152 mm in length and approximately 12.6 mm in width throughout.

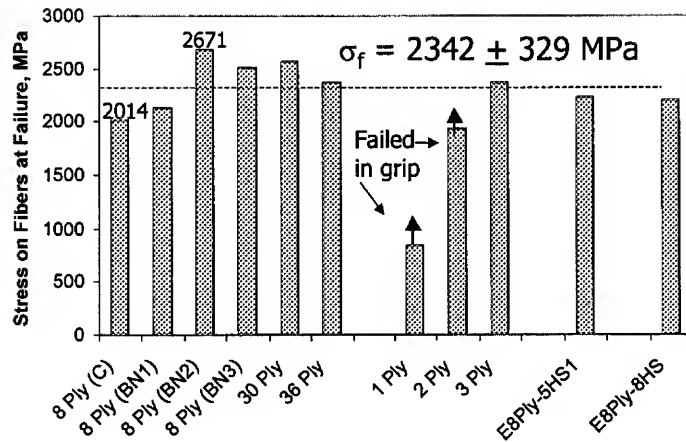
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Tensile Stress-Strain Behavior of Different HiNicalon-CVI SIC Composites



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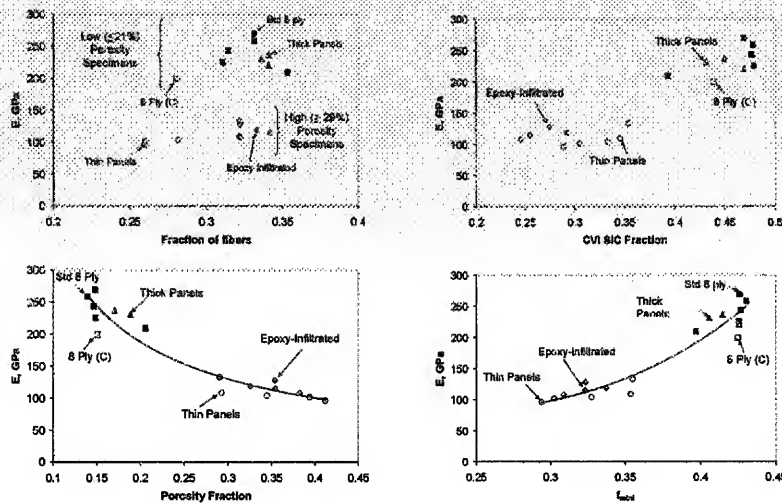
Stress on Fibers at Failure for Different CVI SiC Composite Specimens



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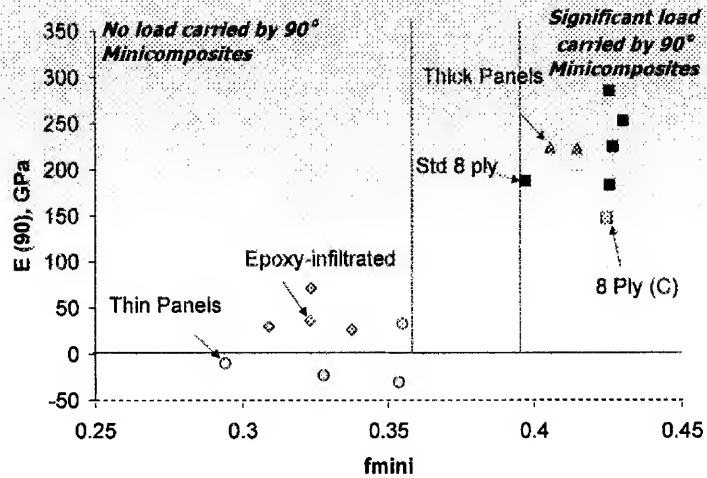
Effect of Various Physical Properties on Elastic Modulus of Composites



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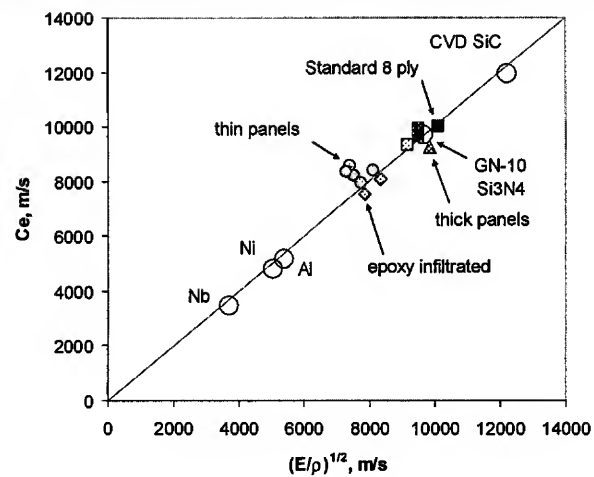
Effective Elastic Modulus of the 90° Minicomposites



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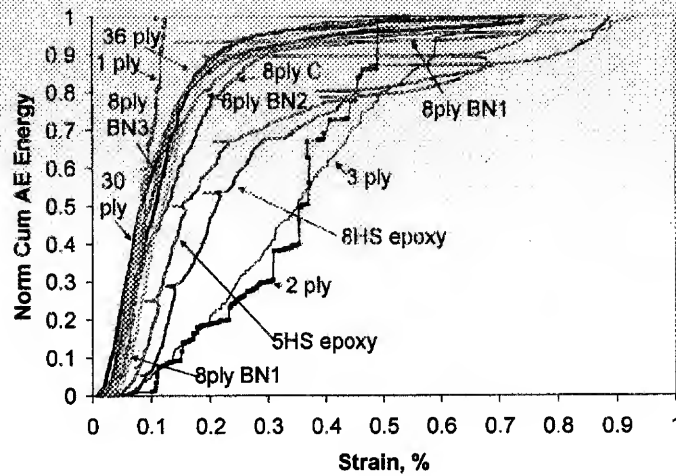
Measured Speed of Sound versus Measured $(E/\rho)^{1/2}$



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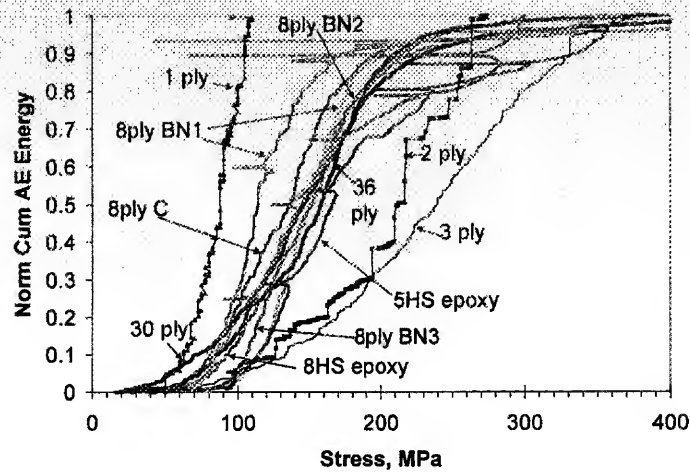
Normalized Cumulative AE Energy versus Strain



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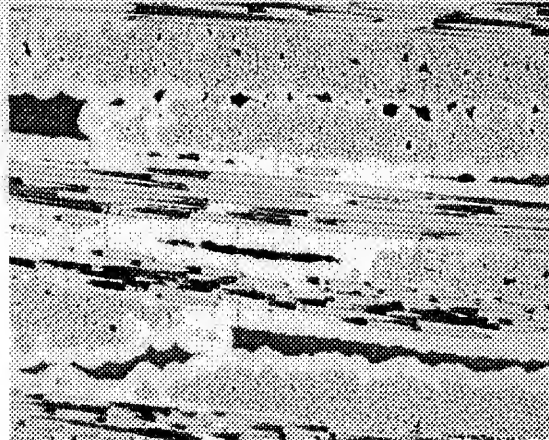
Normalized Cumulative AE Energy versus Stress



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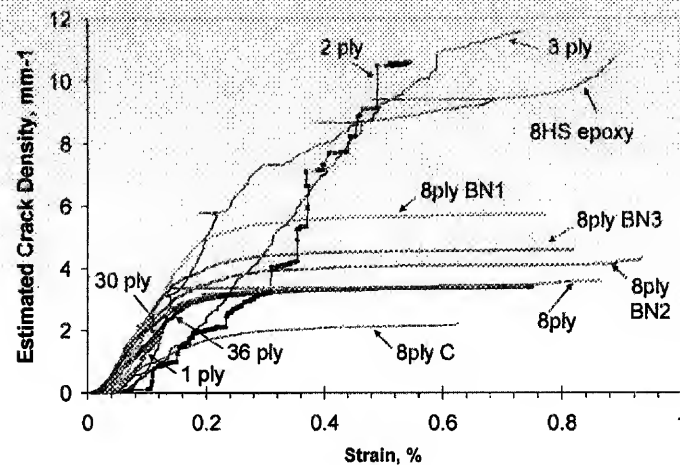
Polished Longitudinal Section Showing Matrix Cracks in 8ply BN3



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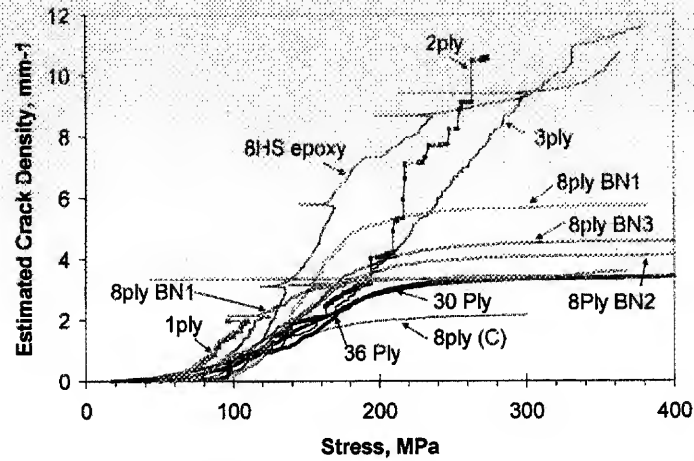
Estimated Crack Density versus Strain



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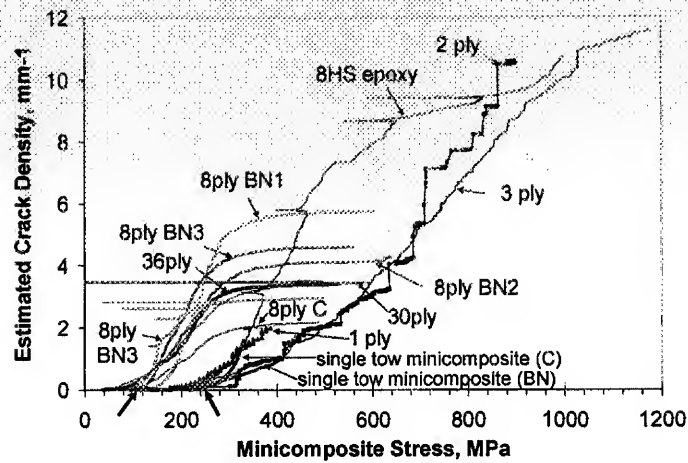
Estimated Crack Density versus Stress



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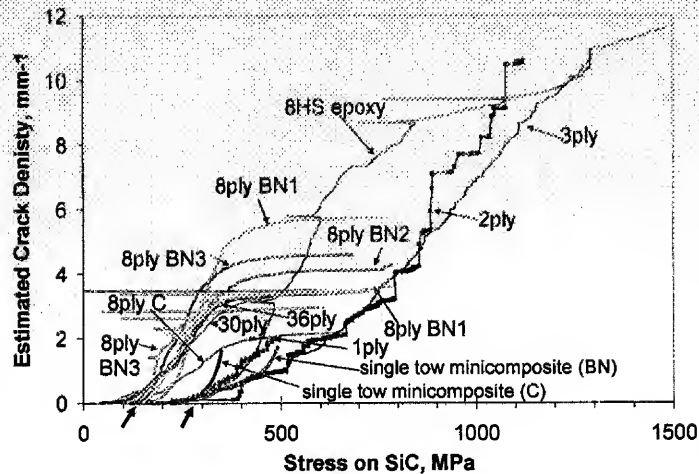
Estimated Crack Density versus Stress on Load-Bearing Minicomposites



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Estimated Crack Density versus Stress on SiC



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Effect of Composite Thickness Summary and Conclusions

- The effect of constituent content on elastic modulus and matrix cracking behavior not only depends on the relative amounts of constituents, but also on the effectiveness of the structure, i.e., 90° minicomposites, to carry load.
- Lower density composites have very little load-carrying contribution from 90° minicomposites when loaded in the 0° direction.
- Higher density composites were affected by 90° minicomposites as low-stress flaw sources, whereas the matrix cracking behavior of low density 2D woven composites were not and behave very much like single tow minicomposites as opposed to high density 2D woven composites.

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